CONFERENCE SUMMARY

Compiled by David Beaty, Lars Borg, David Draper, Walter Kiefer, Jim Papike, Kevin Righter, Chip Shearer, Sue Smrekar, Jeff Taylor

Correspondence author: Dave Beaty (JPL/Caltech), David.W.Beaty@jpl.nasa.gov, 818-354-7968

CL#12-4839

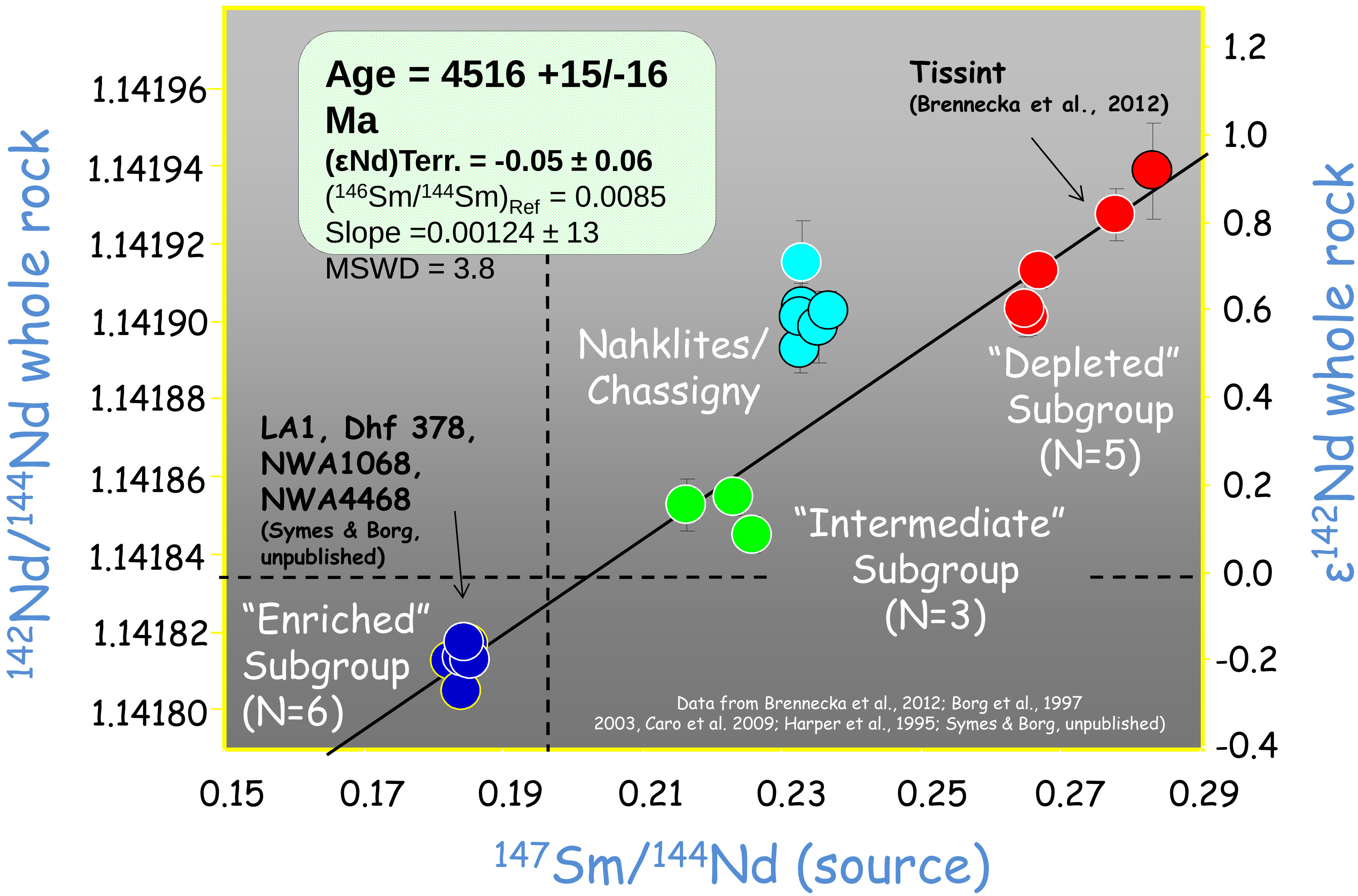
Top things we know about the martian mantle

1. Petrologic Character.
   a) The martian mantle is richer in Fe (Mg# 75-80) and Na (0.5-0.9 wt. %) than Earth's mantle (Mg# 89; 0.35 wt %, respectively). The martian mantle is oxidized (mostly IW±0.5 or so), with a restricted range in oxidation state (~IW-1 to ~IW+3) compared to early Earth (IW-2) and its later range of oxidation state (IW to IW+9).
   b) The martian mantle has undergone a much more severe geochemical depletion than has the mantle of Earth. Key measure: The highest epsilon neodymium for Earth rocks is a little over +10; for Mars, it's +50 or more, representing a couple orders of magnitude of stronger depletion.

Top things we know about the martian mantle

2. Origin.
    - Differentiation of the planet to form the mantle, and differentiation of the mantle itself, occurred as a result of fractional crystallization of a magma ocean.
    - The martian mantle is old: 4520 Ma.
    - Magma ocean differentiated very rapidly, tens of Ma.
3. Heterogeneity. The martian mantle is chemically extremely heterogeneous (by comparison to Earth's mantle). Once the mantle formed it did not homogenize through mixing.
4. Thermal history. Due to its size, the martian mantle cooled more rapidly than Earth. The effects of the cooler temperature on volcanism were partially offset by a mantle composition that melts at lower temperature than Earth's mantle.
5. Mantle Convection. Volcanism has been an important process throughout martian history, extending essentially to the present day. The majority of martian volcanism is likely due to adiabatic decompression melting driven by mantle convection, possibly up to the present.

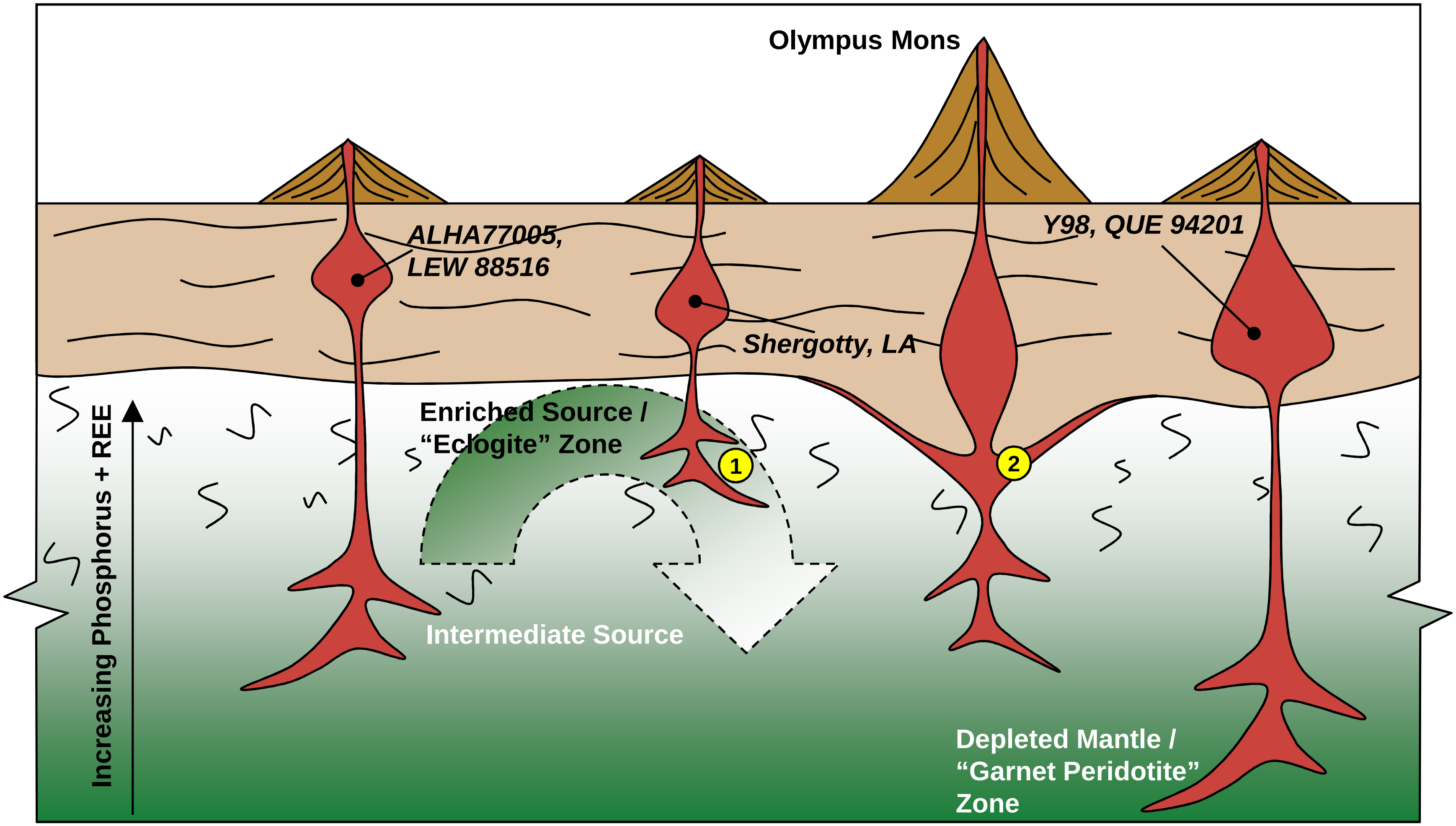
1. Origin, Age



From L. E. Borg, S. J. Symes, N. Marks, A. M. Gaffney, and C. K. Shearer

2. Mantle Petrology

Magmas as mantle probes



From J.J. Papike, P.V. Burger, C.K. Shearer and F.M. McCubbin

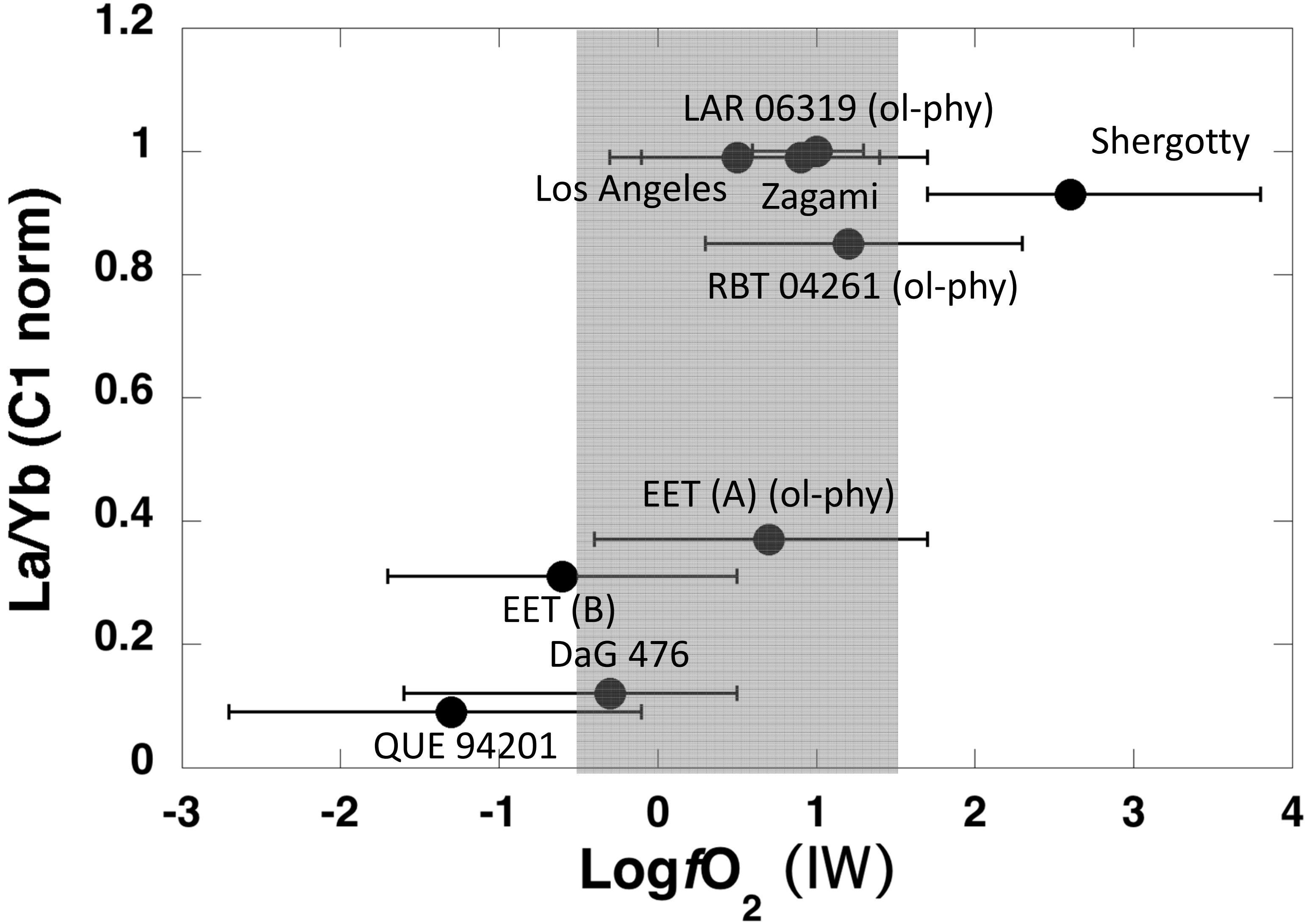
Bulk Chemistry Considerations

- Wänke and Dreibus bulk Mars composition model still quite good
- Mars clearly enriched in FeO compared to Earth
- K and other moderately volatile elements depleted by factors of a few cf CI chondrites
- Highly volatile elements have roughly uniform depletions cf CI chondrites, ~0.03
- Water content about the same as Earth (D/H also seems to be the same)

Discussion: However, some major parts of the Earth's mantle are wetter and in fact water is called upon as the main flux for melting

From Jeff Taylor

Mantle Oxidation State



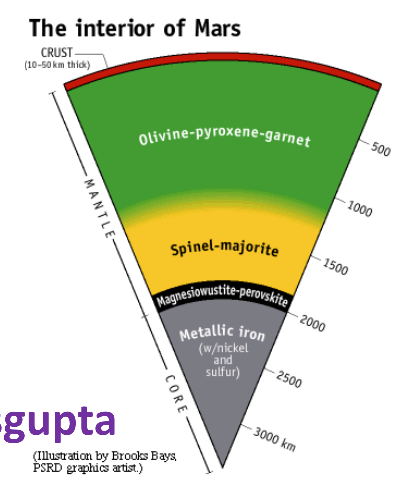
fO_2 estimates based on <u>the pyroxene Eu oxybarometer</u> indicate a range of mantle redox (~IW-1 to ~IW+2).

From Mini Wadhwa

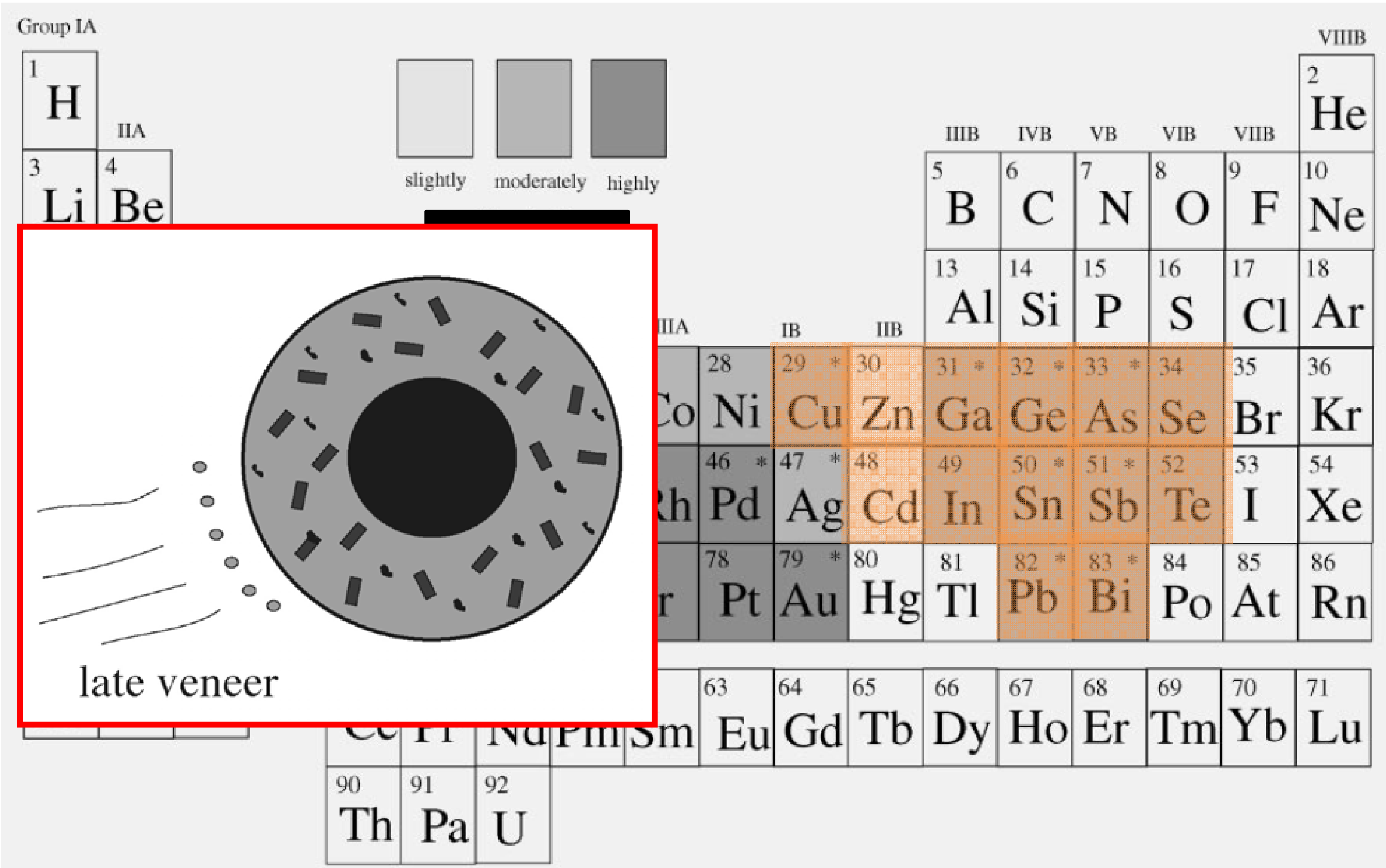
Estimates of P-T of basalt formation

- Inverse Experimental Modeling Approach
  - Meteorites:
    - Yamato 980459 (Musselwhite et al. 2006)
    - NWA 1068 (Filiberto et al. 2010)
  - Surface Basalts
    - Humphrey (Monders et al. 2007; Filiberto et al. 2008)
    - Fastball (Filiberto et al. 2010)
- Geochemical Modeling
  - Ol-Melt Mg-exchange thermometry (Putirka 2005)
    - Surface Basalts (Filiberto & Dasgupta 2010)
  - Silica-activity in the melt barometery (Lee 2009)
    - Surface Basalts (Filiberto & Dasgupta 2010)
  - pMELTS calculations
    - NWA 5789 (Gross et al. 2011)
    - NWA 2990/5960/**6234**/6710 (Gross et al. submitted)
- Early Mars mantle ~200K cooler than Early Earth

From Justin Filiberto and Rajdeep Dasgupta



Volatile siderophile elements - Can be used to place constraints on accretion models



From K. Righter and M. Humayun

Importance of water in the Martian interior

- **Planetary accretion models**
- **Magmatism**
  - Water lowers the solidus of mantle lithologies

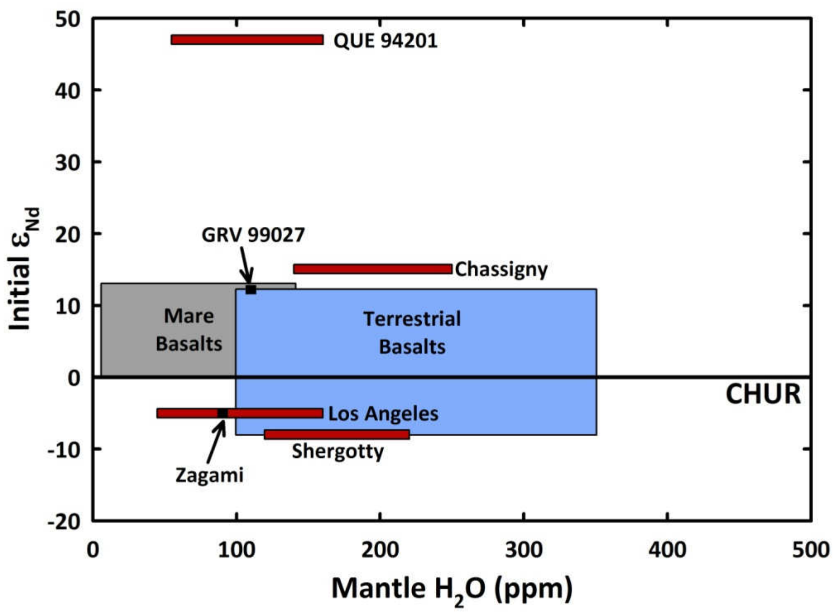
    (Gaetani and Grove, 1998; Green, 1973; Hirose and Kawamoto, 1995; Médard and Grove, 2008)
  - Magma transfer and eruption style
- **Rheology**
  - Presence of water in olivine makes it weaker

    (Chopra and Paterson, 1984; Dixon et al., 2004; Drury, 1991; Hirth and Kohlstedt, 1996; Hirth et al., 2000; Justice et al., 1982; Karato, 1993; 2010; Mackwell et al., 1985; Mei and Kohlstedt, 2000; Walker et al., 2007)
- **Thermal evolution**
- **Seismic wave attenuation**

  (Jung and Karato, 2001; Karato, 2004; 2006)

From Anne Peslier

Volatiles in the Mantle and Lower Crust

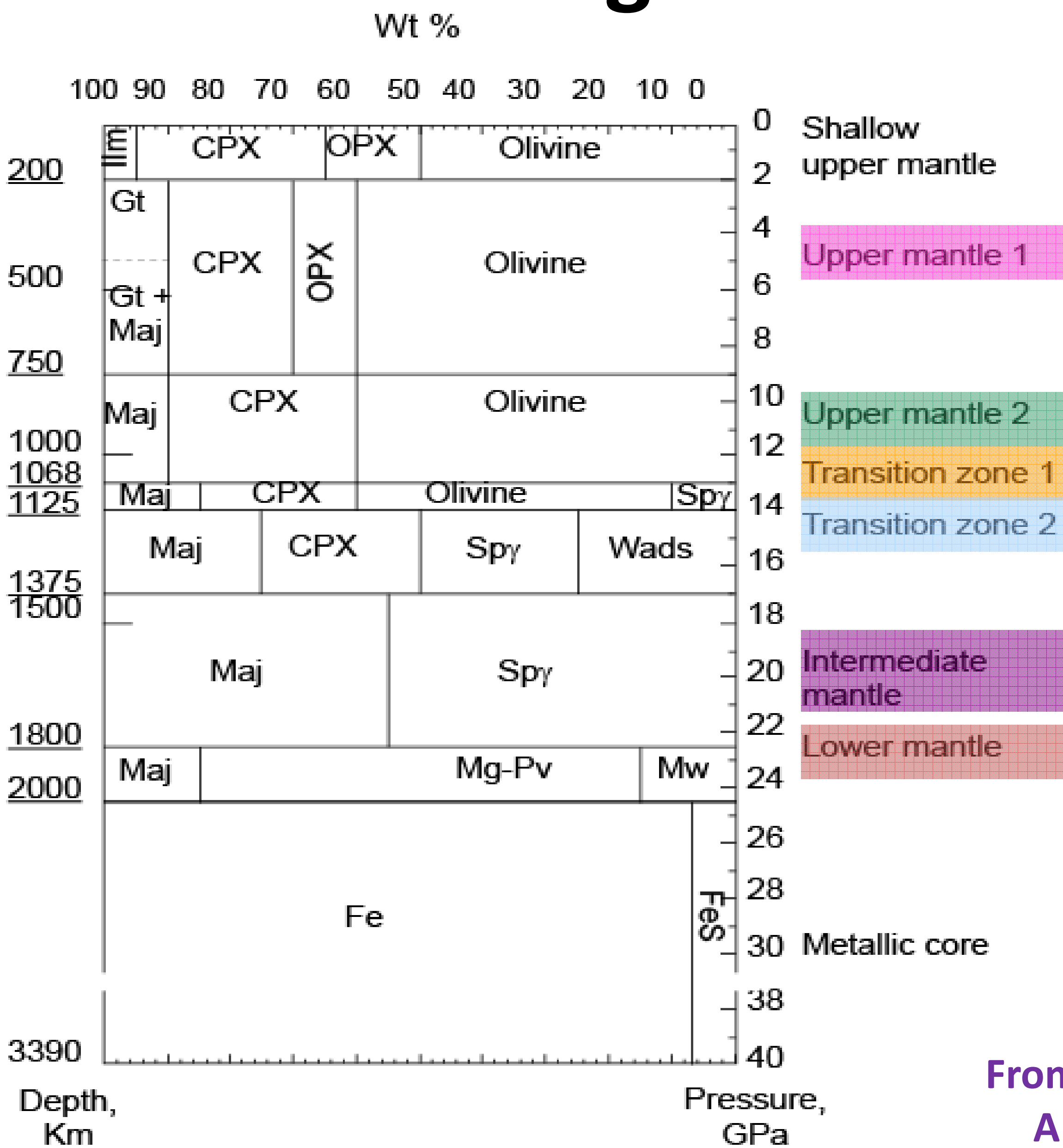


From McCubbin et al. (2012) *Geology*

- SNC sources contained water
  - Independent of enrichment
- Mantle reduced, may be graphite saturated
- Hydrous magmas may have crystallized volatile-bearing mineral assemblages in crust

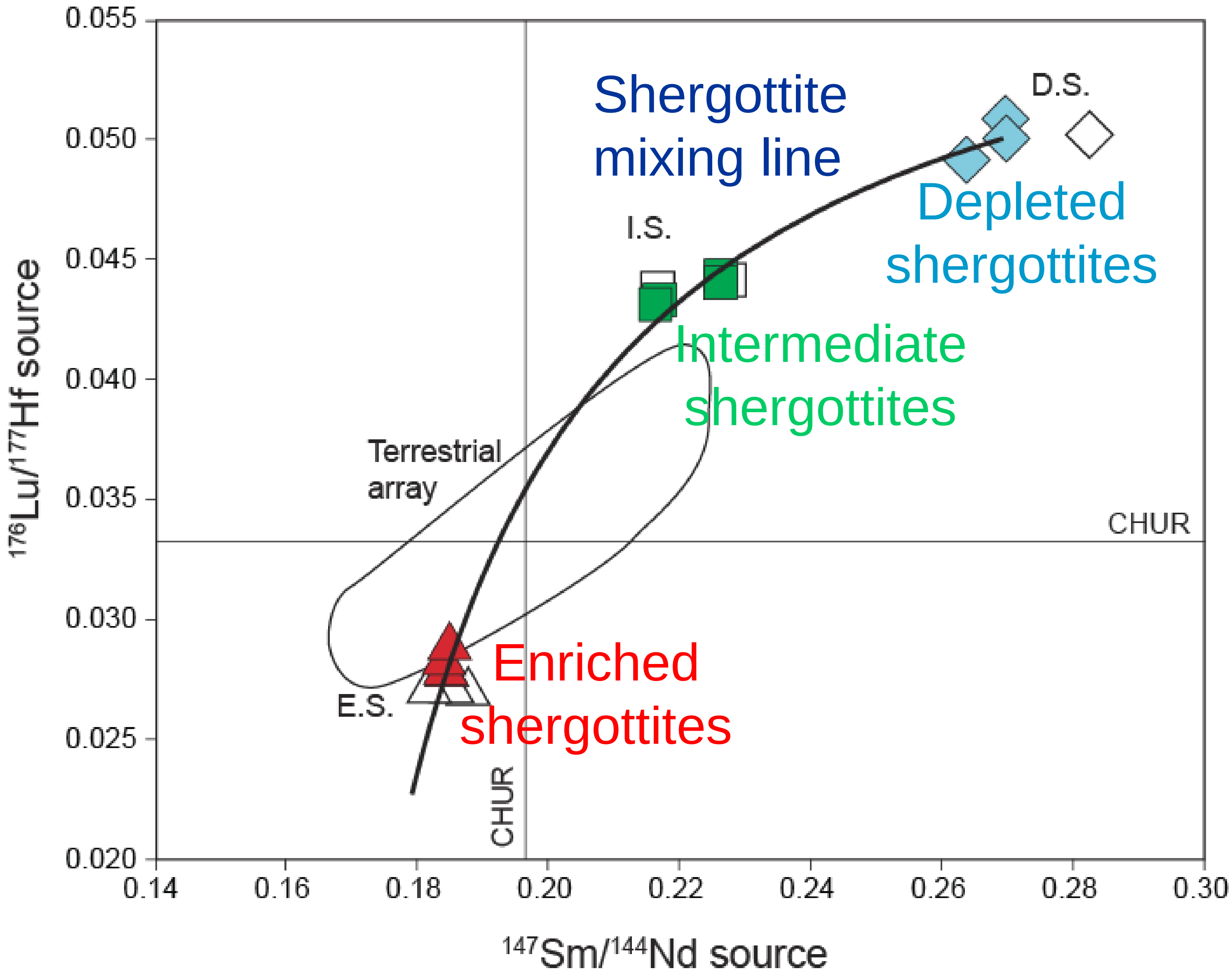
From Francis M. McCubbin and Stephen M. Elardo

Mantle Mineralogical Model



From V. Debaille & A.D. Brandon

3. Heterogeneity



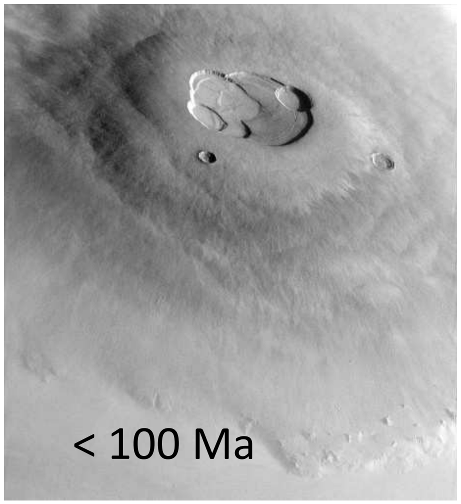
From V. Debaille & A.D. Brandon

4. Temperature: Earth vs. Mars

- Mars: Mg # ~ 75-80, alkalis ~ 0.5 weight %
- Earth: Mg # 89, alkalis 0.35 weight %
- Predicted solidus reduction on Mars
  - 1 GPa: Alkalis 15 °C, Mg # 11-17 °C
  - 3 GPa: Alkalis 20 °C, Mg # 21-32 °C
- Combined effect suggests Mars primitive mantle dry solidus is ~ 30-50 °C lower than Earth solidus.
- Effect is most important on early Mars. Present-day effect will be smaller (Mg # effect persists, alkali effect decreases with time).

From Walter S. Kiefer, Justin Filiberto, and Constantin Sandu

5. Mantle Convection



• Geologic mapping and meteorite isotopes both imply Mars was volcanically active from its formation into the recent past.

• Implies adiabatic decompression melting and hence mantle convection have been important throughout martian history.

Discussion: stated too strongly?

• Preservation of large isotopic anomalies requires long-term separation of at least 2 distinct mantle reservoirs.

• Perhaps Tharsis and Elysium are these separate reservoirs (testable with sample return).

From Walter S. Kiefer, Justin Filiberto, and Constantin Sandu

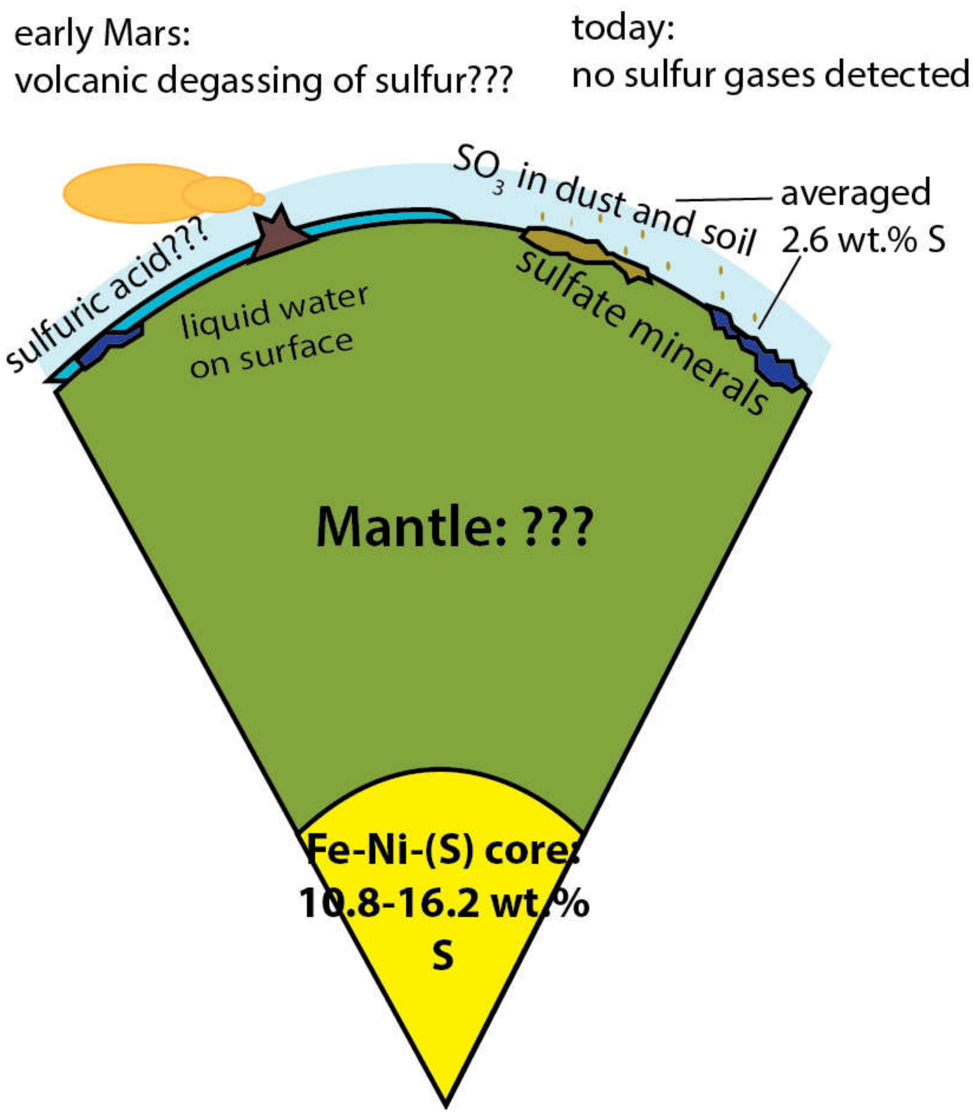
Top things we don't know about the martian mantle

1. Physical structure
2. Thermal State/History. What is the thermal state and history of the martian mantle (and the interior in general)?
3. Process of magma generation. Where?, when?, how?
4. Heterogeneity. What is the extent of compositional heterogeneities in the mantle?
5. Volatile content of the mantle (esp. C, H, O, S)
6. Mineralogy. What is the mineralogical structure of the mantle?
7. Convection. How has the vigor and pattern of mantle convection varied with time?

Many details of our understanding of the petrologic character of the mantle are dependent on interpretations of magmatic liquid compositions using rocks whose bulk chemistry has been affected by crystal accumulation/loss, weathering, and alteration. How will these conclusions be refined by the study of rocks in the for which igneous liquid chemistry can be unambiguously interpreted?

Backup Slides

Sulfur Concentration of Martian Magmas

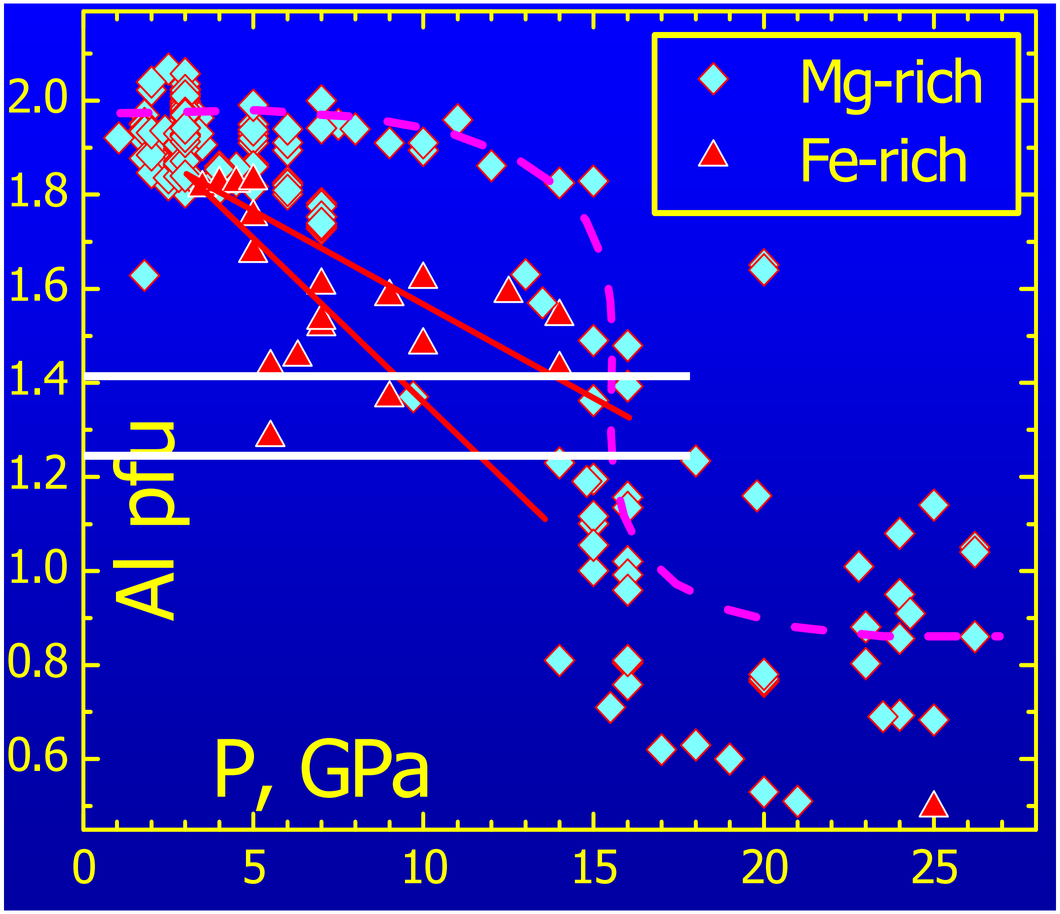


1. How does S behave in martian magmas?
2. What is the likely fluxes of S volatiles from martian interior to the atmosphere?
3. How could Mars get so much S?

What is the sulfur solubility of martian magmas?

From Shuo Ding and Rajdeep Dasgupta

Depth of Garnet Crystallization



- 1.2 – 1.4 Al pfu corresponds to 11-12 up to 15+ GPa (~1200 – 1500 km)
- Roughly in the middle of range inferred from CaO/Al_2O_3 alone
- Consistent with Righter's estimate of 14 GPa (this morning)

From David S. Draper